

Wood and Charcoal Anatomy of Eight Charcoal-producing Wood Species in Central Sudan

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DEDICATION

To the Soul of my Father

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ABSTRACT

Title: Wood and Charcoal Anatomy of Eight Charcoal-producing Wood Species in Central Sudan.

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The objective of this research was to study the wood and charcoal anatomy of charcoal-producing tree species and to investigate the alteration in wood macrostructure induced by charring.

Eight hardwood species that are used for charcoal production in Central Sudan, were selected. The eight species were *Acacia nilotica*, *Anogeissus leiocarpus*, *Acacia senegal*, *Acacia mellifera*, *Balanites aegyptiaca*, *Acacia seyal*, *Eucalyptus camaldulensis* and *Prosopis chilensis*. Each species was represented by five randomly chosen branches for each tree and these branches were felled. One meter length with mid diameter ranged between 5 and 10cm were cross-cut as wood samples (billets), some of these samples were obtained from the stems and others from branches of each tree. A 10cm long disc was taken from one end of the billets and used for the preparation of the samples needed to study wood micro-structure by using, a grid, computer screen (monitor), camera and light microscope. The other parts of the billets (about 90cm long) was used to produce charcoal to study its macro-structure by using hand lens and constructing an identification key to distinguish the wood species from which charcoal was produced.

The results revealed great wood variation among charcoal-producing species in the proportion of wood substance, distinctiveness of growth ring and the quantitative and qualitative characteristics of vessels, fiber, parenchyma and wood ray.

In the charcoalified wood of all species, the fibers were not distinct. Some of the macro-anatomical features, which were distinct in the wood samples, could not be seen in the charcoal samples of the same species (e.g. parenchyma arrangement and rays). The variation in the macro-anatomical characteristics of charcoal among species was sufficient to facilitate identification of the wood from which it was produced. A dichotomous key was prepared to distinguish among the studied species.

مستخلص البحث

عنوان البحث: التركيب التشريحي لأخشاب وفحم ثمانية أنواع شجرية تستخدم لإنتاج الفحم بوسط السودان
الطالبة: حياة محمد بن مصطفى حقار

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CHAPTER I

INTRODUCTION

Wood is composed of many small cells and its structure is determined by the type, size, shape, and arrangement of these cells. The structure and characteristics of wood (and charcoal) can vary between species. Hardwood species are composed of four types of cells, namely, vessels, fiber, parenchyma and tracheids.

Sudan has a rich variety of tree species, and the wood produced from each of these has unique structure. The differences in wood structure and properties allow for the manufacture of wood-based products with many different appearances and uses for millennia for many purposes one of its primary uses is as fuel. It is also used for making artworks, furniture, tools and weapons, and as a construction material. Since wood is popular and useful material, it is important to be able to distinguish the wood of one species from another. For example, how would a manufacturer tell the difference between the many hardwood species available in Sudan that can be used for furniture making? (FNC. 1995).

This property makes wood one of the major sources of fuel in the world economy because of the relative abundance and the renewable nature of the supply . It is also opens many possibilities for deriving basic chemicals from wood, such as alcohols and gaseous compounds. The national forest products demand survey (FNC. 1995) estimated that about 71% of the total oil equivalent of energy consumption was in the form of wood fuels, while 15% was from petroleum. The total amount of fuel wood consumed in terms of final energy was equivalent to about 6.6 tone oil equivalent (TOE) about 46% of volume of fuel wood was used for charcoal making (FNC. 1995).

Biomass energy (fire wood, charcoal and residues). Composed 78% of primary energy consumption in Sudan, which is equivalent to 11.3 million TOE (ME. 2005) .

However, some species are preferred for charcoal making such as *Acacia seyal* var *seyal*, *Acacia melfiera* and *Balanites aegyptica* (Abdel Nour. 1984). *Acacia seyal* is a widespread species in the Sudan. Its charcoal have high heating value, it is with no sparkles and preferred by both the charcoal makers and consumers (Abdel Nour. 1984). The species mostly used for charcoal production in Central Sudan include *Combretum glutinosum* (Habil), *Dalbergia melanoxylon* (abanose) and *Acacia leata* (alshubahi), *Acacia seyal* Del. Var. *fistula*, (alsafar), and *Prosopis africana*, (abousuroge).

Wood Charcoal is formed when wood is burnt under limited oxygen supply (Figueiral 1999). However, during the carbonization process, considerable anatomical changes occur, such as tangential and radial shrinkage (Slocum *et al.* 1978), the homogenization of the cell walls (wall thickness), in which the middle lamella loses its identity, fuses with the two adjacent secondary walls and cell size. (Jones and Chaloner 1991; Jones 1993).

Because charcoal is chemically inert and highly resistant to microbial attack, it retains enough anatomical characteristics to allow identification of the wood from which it comes, to the family or genus level (Prior & Gasson 1993).

The objectives of this study were:

- To study the wood macro- and micro-structure (anatomical properties) of eight charcoal-producing wood species.
- To study the macro-structure of the charcoal produced from these species.
- To develop or to investigate the possibility of developing an identification key for charcoal produced from these species.

CHAPTER II

LITERATURE REVIEW

2.1. General

Like all living tissues, wood is built of individual units, (the cells). These cells are either tube-like, with blunt or pointed ends, or brick-shaped. They differ considerably in size and shape and each is adapted to one or more of the primary functions of the stem. Commercial woods fall into two main groups, the softwoods and hardwoods. Softwoods are produced by gymnosperm trees (also known as conifers). Hardwoods are produced by trees of the dicotyledons group of the angiosperms, also known as broad-leaved trees (Panshin and de Zeeuw. 1980; Desch and Dinwoodie. 1981).

Most of wood cells structure characteristics are best viewed from the wood and charcoal surface. Because of the way trees grow, you can generally view three very different surfaces of wood. Wood surfaces are classified into three categories, or geometric planes of reference, that indicate the type of surface uncovered after a cut has been made. The three reference planes are the cross-section, longitudinal radial-section and longitudinal tangential-section (Panshin and de Zeeuw. 1980; Desch and Dinwoodie. 1981).

The transverse or cross-section is produced by cutting the cells perpendicular to the grain direction of growth in the tree. It is the same surface seen on a stump after felling a tree; it is what you see when you look at the end of a board or log. Growth rings may appear as a circle or part of a circle on this surface. The radial surface parallels to the stem and passes through the pith. If you split a log in half, you will produce two radial surfaces. The tangential surface is named because it is the surface tangent to the growth rings. It is perpendicular to the direction of the wood rays. The three surfaces of wood are important because wood structures appear very different depending on which surface is being viewed (University of Kentucky. 1997). Hence, it is important to determine which reference plane you are viewing when identifying wood or charcoal, because cell structure in three directions varies, based on orientation (Panshin and de Zeeuw. 1980).

2.2. Hardwood Structure

The structure of hardwoods is more complex in terms of cell and tissue types than softwoods. Hardwoods are composed of at least four major kinds of cells, namely, vessel elements, fibers, tracheids, and parenchyma cells (Panshin and de Zeeuw. 1980). Each of these elements may constitute 15% or more of the volume of hardwood xylem (Haygreen and Bowyer. 1985). They differ in their proportion and arrangement from one species to another and within the individual tree (Panshin and de Zeeuw. 1980). These elements will be described in the following sections.

2.2.1. Vessels Elements

Vessel elements are generally much shorter and larger in diameter than other types of longitudinal cells. The short length of vessel elements is traceable to the fact that they often do not grow in length during the maturation process and may become even shorter than the cambial initials from which they were produced (Jane *et al*, 1970).

The main function of vessel elements is water conduction. Vessel elements can vary greatly in size, number and spacing from one species to another, and from early wood to latewood (Holbrook, N. M. 2001). The vessels formed in the early wood are much larger and more crowded than those formed in the latewood (Core *et al*, (1979). Some species, have vessel elements that are extremely large and numerous. Other species have vessel elements that are uniform in size and number, and are evenly spaced throughout the growth ring. By using a hand lens, you can determine if vessel elements are present or not. (Holbrook, N. M. 2001).

Vessels are composite tube-like structures of indeterminate length. They are made up of individual vessel elements, which are fused together end to end with complete or partial disappearance of end walls (Carlquist. 1984).

2.2.1.1 Vessel distribution

A major step in identifying hardwoods is to observe and categorize how the change, or transition, in pore size occurs from earlywood to latewood (Hoadley. 1990; Panshin and Zeeuw. 1980). They mentioned that within a

growth ring, there are three general classes for this earlywood/latewood transition, namely.

Ring-porous hardwoods: For some groups of species (e.g. oaks and elms) the earlywood/latewood transition occurs abruptly and is very distinct. Within each growth ring, a band of large crowded earlywood vessels is clearly visible to the naked eye, after which a band of latewood vessel appears much smaller and requires the use of a hand lens to see.

Semi-ring-porous hardwoods: For another group of species (e.g. black walnut, butternut and hickory) the pore transition from large to small diameter vessels within a growth ring is gradual. The pores in the earlywood zone have a large diameters that gradually decrease in size as pores enter the latewood zone.

Diffuse-porous hardwoods: The last group of species has vessels that are uniform in size and distribution across the entire the cross-section (yellow poplar, gum and maple). These vessels are usually small, uniform in size and are very difficult to see with the naked eye (a hand lens is needed).

2.2.1.2. Vessel Arrangement

Vessel elements (pores) can be described by their position relative to each other in a cross-section. Different species have unique vessel arrangements.

Solitary pores: Pore arrangement where single pores do not touch other pores; often evenly spaced in across-section.

Pore multiples: Pore arrangement where two to five pores appear grouped together. Pore multiples usually occur in radial rows (cotton-wood), but can occur in both radial and tangential direction (Kentucky coffee tree).

Pore chains: Pore arrangement where pore multiples appear in radial direction only pores retains their circular shape (pores retained their oval shape).

Nested pores (in clusters): Pore arrangement where larger numbers of pores contact each other both radially and tangentially.

Wavy bands: Pores are arranged in irregular, concentric bands. Also called *ulmiform* because this characteristic is distinctive of all elms and also hackberry. <http://www.utextension.utk.edu/>).

Carlquist. (1984) noted that the appearance, based on orientation in which vessels are grouped as seen in transverse section, has been used for the recognition of vessel types. Radial multiples and sometimes vessels in chains are said to occur when vessels are in contact in radial series. Radial multiples theoretically offer away for the conductive system to form new vessels that can take over the function of earlier-formed vessels without alteration of the conductive pathway. Tangential aggregation is the tangential band of vessels that represents not a single, but several phenomena. In one of these, there are large non-grouped early wood vessels followed by tangential bands of smaller vessels (Carlquist. 1987).

2.2.2. Fiber Cells

Fibers are generally long, tapered and usually thick walled cells of hardwood xylem (Jane et al. 1970). Hardwood fiber tends to be rounded in cross section as compared to the nearly rectangular shape of softwood tracheid (Haygreen and Bowyer 1989). These narrow cells have pointed, closed ends. Two types of fiber are recognized, namely, libriform fibers and fiber tracheids. Fiber tracheids are generally, relative thick-walled, fibrous cells with pointed ends and bordered pits. Libriform fibers are elongated fibrous cells which differ from fiber tracheids in possessing simple pits (Core et al. 1979).

2.2.3. Wood Parenchyma Cells.

Wood parenchyma cells are small, thin-walled, storage units, in hardwoods. Longitudinal form of parenchyma is often divided into a number of smaller cells through the formation of cross walls during the process of cell maturation (Hay green and Bowyer. 1989). Parenchyma cells are often very small and difficult to see. However, there are many species with visible and unique arrangements of parenchyma cells that offer a clear structural feature for decisive identification (Hoadley. 1990). Longitudinal parenchyma is relatively rare in the softwood species, usually not more than 1-2% of the volume of those woods in which it occurs. However, it is often quiet

significant in hardwoods. Some hardwoods have up to 24% of their volume made of longitudinal parenchyma cells, and certain species with no longitudinal parenchyma (Panshin and de Zeeuw. 1980).

Longitudinal parenchyma displays a great variety in distribution and arrangement. Consequently, wood parenchyma (and rays) are very useful features for distinguishing between different hardwoods. There are two types of distribution, namely, Paratracheal and Apotracheal parenchyma. The major difference between them is that Para tracheal parenchyma is separated from pores by fibers or rays, while Apo tracheal parenchyma makes contact with the vessel elements (The associated Agricultural Extension Service Website: <http://www.utextension.utk.edu/>).

The two types can be further subdivided into various arrangements. Apo tracheal are divided into terminal, diffuse and diffuse in aggregate (or met tracheal), and Paratracheal divided into scanty, vasicentric, aliform and confluent (Panshin and de Zeeuw. 1980; Desch and Dinwoodie. 1981). Further subdivisions are possible, which, however, grade into one of the previously mentioned divisions (Desch and Dinwoodie. 1981).

2.2.4. Rays Cells

Once the pore distribution and arrangement have been identified, it is important to look at the size and arrangement of wood rays.

Wood rays are seen as narrow stripes or lines that extend across the growth rings in the radial direction- from the bark to the center of the tree (Hoadley. 1990). Hardwood rays vary greatly in size and are composed entirely of parenchyma cells. The ray parenchyma cells, however, vary considerably in size and shape. When the ray cells are all of approximately the same size and shape, the rays are termed homocellular rays. The rays are said to be heterocellular if they contain more than one type of ray parenchyma cells. (Nasroun. 1987). Hoadley (1990) noted that wood rays function to transport food and water horizontally across the diameter of a tree.

2.3. Charcoal

2.3.1. General

Sixty percent of all wood taken from the world forest is believed to be burned as fuel, either directly or after conversion into charcoal (FAO. 1987). Charcoal is the residue obtained when wood or other woody material such as bark is heated in a closed space above 300° C without free access of air and allowing it to cool to normal temperature without entry of air (Booth. 1983). There are several types of carbonization kilns including the earth mound, earth pit, brick kilns, metal (steel) kilns and oil drum kilns (FAO. 1987).

Charcoal is woodfuel in an alternative form. It has a higher fuel value than ordinary wood, both on a volumetric and a weight basis (Desch and Dinwoodie. 1981). Although in preparing the charcoal more than half of the wood's energy is nearly burned away, charcoal is preferred because of its steady and concentrated heat and less in smoke. It can be easily extinguished when the fire is no longer needed. Charcoal also can substitute fossil fuels, which in some places is an urgent need (National Academy of Science. 1983). Desch and Dinwoodie. (1981) noted that the advantages of charcoal over firewood are largely economic when associated with low transport and handling costs per heat unit and the costs are more than offsetting the cost of production. Charcoal makes wood energy easier and cheaper to transport.

Charcoal unlike wood cannot be affected by insects or decay fungi. It can be stored indefinitely without deterioration. Charcoal has a fine porous structure which aids the combustion of the carbon and tars which it contains. It burns with short hot flame without production of smoke. Charcoal when ignited burns steadily giving out much of its heat by the radiation from the burning fuel bed. Wood, on the other hand, burns with a flame and requires a different design of burning apparatus to achieve maximum efficiency (Booth. 1983).

Because of its porous structure, finely divided charcoal is highly efficient agent for filtering the adsorption of gases and of solids from solution. It is used in sugar refining, in water purification, in the purification of factory air

and in gas masks. Wood charcoal can remove coloring agents from solutions (FAO. 1987).

2.3.2. Wood Charcoal Anatomy

Charcoal is formed when wood is burnt under oxygen-depleted conditions (Figueiral. 1999). Because charcoal is chemically inert and highly resistant to microbial attack, it retains enough anatomical characteristics to allow identification of the wood from which it comes, to the family or genus level (Prior and Gasson. 1993). Moreover, much information about the local flora, cultural practices, and ecological environment can be drawn from charcoal remains found at archaeological sites.(Angeles. 2001).

Traditionally, the anatomical study of charcoal has been carried out on freshly split radial or tangential surfaces, which are then observed under the dissecting, reflected light, or scanning electron microscope (Figueiral. 1999). Because split surfaces of charcoal have a dark, shining color and are not completely flat, sometimes they do not show diagnostic features as clearly as do clean, flat wood surfaces. Its brittleness or degree of deterioration nearly prohibits thin sectioning of charcoal for the light microscope without tedious embedding procedures or very drastic softening procedures (Figueiral. 1999). Therefore, vessel diameter, pit size, ray height, and vessel frequency all have to be measured under the dissecting microscope with incident illumination. However, the highly reflective nature of the charcoal surface increases the difficulty of observation and measurement.

Smith and Gannon. (1972); Ruzin. (1999) used epoxy resin for embedding charcoal. That method requires long periods of dehydration in acetone and infiltration in gradually increasing concentrations of epoxy resin dissolved in acetone. A total of 10 days would be necessary for specimen preparation prior to sectioning. According to Ruzin. (1999), it is possible to obtain sections 8-10 μ m thick with epoxy-embedded charcoal. An alternative procedure is to use a scanning electron microscope (SEM), but this solution is economically and logistically impractical for many wood anatomy laboratories.

Angeles. (2001) noted that accurate and fast identification of charcoal samples call for fast, reliable and inexpensive techniques for charcoal

identification, which can be carried out even in the field. He introduced a combination of techniques to overcome some of the problems presented by the previous methods. These problems were related to trouble with the high reflectance of fractured surfaces when observations are made using light microscopy, unavailability of equipment, and time-consuming, sample-altering methodologies. . He used various techniques to study charcoal anatomy including incident light and SEM microscopy. He used transverse surfaces painted with correction fluid for determination of vessel grouping and distribution, and indirect replicas of transverse and longitudinal surfaces made of nail polish for observation of other features including inter-vessel pit apertures, and ray size and composition. He argued that good results are obtained even with a routine light microscope (Angeles. 2001).

During the carbonization process, considerable anatomical changes occur, such as tangential and radial shrinkage (Slocum *et al*, 1978), and the homogenization of the cell walls, in which the middle lamella loses its identity and fuses with the two adjacent secondary walls (Jones. 1993). These changes must be taken into account when one is trying to identify species, or trying to reach ecological inferences from charcoal remains (Prior and Gasson. 1993).

Using incident light for observation of charcoal transverse surface under the dissecting microscope, many bright dots were seen as reflections of the light. Rays were seen clearly as bright parallel lines. Vessels looked like darker spots, but not much can be seen of their shape or distribution. After impregnating the cell Lumina with correction fluid, drying up the sample and removing the excess of white material left over the surface, vessel outline showed up very clearly. On the charcoal samples the porosity was found to be diffuse and radial groups of more than five were predominant and a few clusters of four to five were present (Angeles. 2001).

Prior and Gasson. (1993) studied the anatomical changes on charring six African hardwoods. They found weight loss of cubes and quantitative changes in vessels diameter could be due to tangential and radial shrinkage Ray cell height significantly decreased and width is shrinkage after charring at 400° and 700°C. In almost every parameter measured, morphological and anatomical changes were greater in cubes charred at the higher temperature.

Analysis of variance between species showed changes in vessels diameter and ray cell height and width to highly significant ($p \leq 0.001$). Changes in axial parenchyma and fibrous tissue could not be quantified, although qualitative changes are described.

Also, McGinnes *et al*, (1971) and Beall *et al*, (1974), found that white oak and yellow poplar cubes shrank more in the tangential direction than in the radial while Slocum *et al*, (1978) found that tangential and radial shrinkage were greater for oak than hickory, suggested that these difference were due to little understood, complex processes which differed according to the anatomy and chemical composition of the wood.

2.4. Studied Species

The wood samples investigated in this study were collected from eight hardwood species growing in Central Sudan. Their distribution and description are given in the following sections.

2.4.1. *Acacia senegal* (hashab)

Hashab occurs as shrubs or small trees 2-12m high. Bark yellow to light brown or gray, rough, fissuring or flaking. Young branchlets with horizontal, slit-like lenticels. Stipules non-spinescent. Its prickles (black thorns) are in groups of threes (not in pairs like most other acacia species), with the two side thorns curved down words (Harisson and Jakson. 1958; Smith and Montgomery. 1959; El Amin. 1973. and Awuda. 1974). Typically associated with the Sahel zone, it occurs from the red sea to Senegal. Different varieties are also .found in East and Southern Africa (Vogt. 1995). The species has a wide distribution and remarkable adaptability (El A min. 1976). It is a semi arid zone species that is drought resistant and frost hardy (Troup. 1932). It's the most abundant tree species in dry sandy, thorn-scrub areas found in a belt along the southern frontier of the Sahara desert, from Mauritania to Sudan, Ethiopia and Somalia. It also grows in east Africa as for south as Mozambique, the Transvaal and Natal, along the southern east of Arabia and Iran and in Pakistan and western India (NAS. 1979).

2.4.2. *Acacia nilotica* (Sunt)

Medium size tree up to 17m high and 50cm diameter, crown is rounded or umbelliform, much branched, with light foliage. Branches spreading irregular twiggy or crooked, bole straight, short cylindrical. Bark is blackish dark grey, rough and fissured flaking off in elongated fibrous scales. Sapwood white, heartwood deep red –brown, hard, heavy and durable. Wood used for railway sleepers, structural members in building, transmission poles and agricultural implements; tannin obtained from bark and pods (Thirakul. 1984). Found along banks of rivers seasonal water courser rivers and valleys on alluvial light soil basically in Blue Nile, Kordofan, Darfur and Northern Bahr El Gazal (El Amin. 1990).

2.4.3. *Acacia seyal* (Taleh)

There are several sources of literature revealing the morphological description of *Acacia seyal* vary *seyal* (Del and Greenway. 1961; El Amin 1979; Thirakul. 1984; Badi *et.al*, 1989). It is medium size tree up to 17 meters 3 high but 9-10m is regarded as full-size over most of its range. Trunks diameter is 25-30cm. Pole is straight and cylindrical Lateral branches develop obliquely, forming a flat-topped spreading crown. The most conspicuous feature is the bark which is powdery, smooth, or sparsely flaking in large blackish scales, it displays a arrange of colors ranging between red, greenish-yellow or orange red, but the predominant one is the reddish. The young branches are rounded, glabrous with numerous reddish glands. Stipules spine scent.

2.4.4. *Acacia mellifera* (Kitr)

Shrub or small tree, often with several stems, 1-6m high with a more or less rounded crown, often gregarious and forming impenetrable thorny thickets. Bark smooth grey, branchlets pubescent or glabrous, grey brown to purplish black. Prickles in pairs below each node, dark brown to blackish, sharply recurved 2.5-5 (-6) mm long. Leaves pinnate mostly 2-3 pairs, leaflets 1-2, distribution Northern and Central Sudan habitat is dry scrub with trees, deciduous bush land. Spot characters shrub or small tree, prickles black, sharply recurved in pairs 2.5-5mm, leaflets operate oblong. pod flat mostly

5.5.cm long 2 cm broad, straw colored or very pale brown acuminate at end, margin wavy, usually 3-seeded.

Uses: the timber is durable and is used locally in the round for building poles, fencing and other purposes it is used also for fuel and charcoal. Browsed by camels. Used for live hedges (Sahni. 1968).

2.4.5. *Prosopis chilensis* (Mesquite)

A small to medium-size thorny evergreen tree, rarely transcending 8m in height, but on a good site with good quality seed, sometimes reaching up to 15m. Its predominant distinguishing features are as follows: a sprawling form, with multiple stems consisting of long branches which tend to hang down to the ground; bright green foliage; and long (15cm) straw-colored pods which stay on the tree for a long time.

This tree originates from North America and has become naturalized in many parts of the world. It has been widely introduced in Africa; in Sudan.

This species has been planted widely since it is able to grow and survive in harsh conditions, where other species either cannot be established, or grow only very slowly. It has many uses wood and charcoal; it's also durable and can be used in local construction, for fence posts, and in some cases for furniture. Leaves are eaten by live-stock but not to any great extent. The pods make a good fodder. Pods can also be used as a sweet enter, for making alcohol and after the seeds are removed, ground into a meal. Trees are often planted around pumps and waterholes and provide amenity and shade. They are used for hedging and possible they must important use for *P. glandulosa* is as a shelterbelt a round villages and agriculture land to protect against encroaching sand dunes. In Northern Sudan it is regarded as the most useful forestation species for this purpose; effective shelterbelts can be established on pure sand within year from planing.

However, in contrast, in eastern Sudan it is regarded as a major pest, at it has invaded agricultural areas and is also threatening to overwhelm and eradicate indigenes forest (Vogt. 1995)

2.4.6. *Eucalyptus camaldulensis* (Ban; kafur)

It is a medium sized tree usually branching not far above the ground. It may reach 30-40m in height with stout trunk often short and crooked. The bark is smooth, white or grayish in color except near the base of the trunk where it is often rough, the crown is open, widely spreading and irregular. (Brooker *et al*, 2002).

The most southerly occurrence of eucalypts is in southern Tasmania. The species in Tasmania are for the most part also found in Australia mainland (Brooker and Slee. 1996). *Eucalyptus camaldulensis* is found over most of the Australian mainland, except southern Western Australia, south-western South Australia and the Eastern coastal areas of Queensland, New South Wales and Victoria (Chippendale. 1988).

Eucalyptus spp are evergreen woody plants. Most species are in forest of 30-50m in height, others are wood land trees 10-35m high (Proyr. 1976).

The leaves are usually coriaceous, often thick, stiff, highly cutinized and rich in sclerenchyma cells. They are usually alternative, only in few species are they opposite or sub-opposite. Dimensions vary considerably, in the same species, and sometimes on the same tree (FAO. 1981).

Eucalyptus are notable for the high proportion of species which have decorticating bark which results in smooth stems often white and light colored appearance. The bark on young branches of mature trees is smooth while on lower part of the trunk, the rhytidome become more or less persistent and deeply farrowed (FAO. 1981). The flowers are distinguished by the presence of an operculum which is covering the reproductive organs (Pryor. 1976).

Santos. (1997) reported that the flower color varies from white, cream, pink, yellow and red depending upon the species. There are two types of eucalypts flowering, one which flowers once a year and other which flowers most of the year. The fully development seeds in any individual fruit are quite small under natural condition. The ripe seeds will ordinarily germinate within a few days if exposed to outside condition of temperature and moisture (Pryor. 1976).

2.4.7. *Balanties aegyptiaca* (Heglig)

Medium sized tree up to 15m high and 50cm in diameter, easily recognized by it is drooping branchlets or simply by its longitudinally fissured bark, with a fluted bole. Crown spreading usually with dense drooping vertical green branchlets. Branches obtuse, spreading at the ends very branched and mostly crooked.

Bole straight, short, fluted, slightly enlarged and fluted at the base. Bark grey to dark brown, yellowish grey in drier regions, rough, deeply and longitudinally fissured, exposing a yellow colour in the younger parts. Fruits drupes oblong-ellipsoid 3-4cm long and about 2.5cm diameter green and shortly velvety when young. Turning yellow and glabrous when ripe, smooth or wrinkled with a yellow-brown, sticky edible flesh and single hard stone. Wood is yellow, coarse-grained and hard, usually used In local furniture, agricultural implements, joinery and walking sticks, also used as firewood and charcoal (Thriakul. 1984). Widespread throughout the greater part of the Sudan right up to the northern frontier (Sahni. 1968).

2.4.8. *Anogeissus leiocarpus* (Sahab)

Medium size to large tree up to 20m high. Bark grayish white, becoming very dark grey in old trees, fairly smooth, flaking off. Branches often drooping and slender. Leaves alternate, rarely opposite or sub opposite, elliptic to ovate lanceolate, 35cm densely silky becoming pubescent beneath (El A min. 1990).

Or 2-8cm long, 1.2-3.5cm broad, at first densely silky, then laxly pubescent beneath, leaves light green or ash colored (Sahni. 1968). Flowers in globes heads, small, greenish yellow, with a reddish disk with white hairs, petals absent. Fruit in globes cone. Like heads, broadly winged coriaceous, dark grey about 3mm board, beaked by the persistent receptacle (El Amin. 1990; Sahin. 1968). Valuable timber. Sapwood quite large, yellowish nearly, hard.

It is widespread in Kassla, Kordofan, Darfur, Bahr el ghazal .and upper Nile state. In Equatoria state, the species is absent from the east bank of the Nile except for small area within 20Km of Juba. In Yambio district, it is found in the gallery forest. .Specimens from drier areas tend to have smaller leaves and more hairy flowers (El A min. 1990; Sahni. 1968).

CHAPTER III

MATERIALS AND METHODS

3.1. Materials

Wood material used in this investigation comprised eight hardwood species belonging to five families growing in Central Sudan (Table 3.1).

Table 3.1. Local and scientific names and families of the study species.

Species		Family
Local name	Scientific name	
Hashab	<i>Acacia senegal</i>	Fabaceae
Taleh	<i>Acacia seyal</i> var <i>seyal</i>	
Sunt	<i>Acacia nilotica</i> sub spp <i>nilotica</i>	
Kitr	<i>Acacia mellifera</i>	
Heglig	<i>Balanites aegyptiaca</i>	Blanitaceae
Ban (kafur)	<i>Eucalyptus camaldulensis</i>	Myrtaceae
Sahab	<i>Anogeissus leiocarpus</i>	Combretaceae
Mesquite	<i>Prosopis chilensis</i>	Leguminosae

Sample trees of *Acacia. millifera*, *Acacia senegal*, *Acacia seyal*, *Anogeissus leiocarpus*, and *Balanites aegyptiaca* were collected from El Nour (El Azaza) Forest Reserve, which is a natural forest; at a distance of about 6-7 Km southeast of Ed Damazine, Blue Nile State. The total area of the forest is about 4667.17 hectares (11112.3 Feddan)- Other species growing in this forest include

The sample trees of *Acacia nilotica* were collected from Sawlail Forest, which is a man mode forest located on the eastern bank of the Blue Nile River at a distance of about 180 Km southeast of Ar-Rouseiris, Blue Nile State.; the total area of the forest is about 3136 Feddan.

Samples of *Prosopis chilensis* and *Eucalyptus camaldulensis* were obtained from individually growing trees in Shambat area, Khartoum State

3.2. Methods

3.2.1. Wood Samplings

Each species was represented by at least five randomly chosen trees. The trees were felled; one-meter long wood samples (billets) were obtained from the stems and/or branches of each tree. The mid diameters of the billets ranged between 5-10cm.

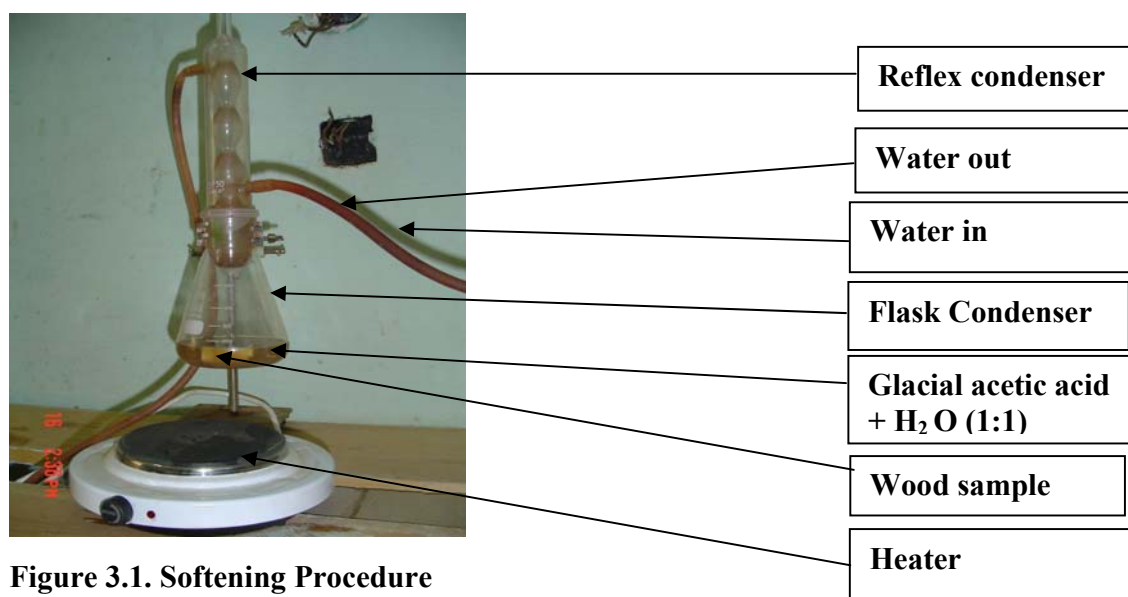
A 10-cm, long disc was removed from one end of the billets and used for the preparation of the samples needed for the anatomical studies. The other parts of the billets (about 90 cm long) were used for charcoal production.

3.2.2. Slide Preparation

Blocks of about 1x1x2 cm were cut by a small hand saw and kept in 50:50 water: glycerin solution ready for the preparation of the wood micro-sections (for microscopic slides) and anatomical description using hand lens with microscopic section.

Softening:

Franklin's softening method was used as cited in Jane (1962). The dry blocks were softened using a mixture of equal parts of glacial acetic acid and hydrogen peroxide. (The blocks were dropped in this mixture, which was contained in a flask that was fitted with a flex condenser, attached with running water (Figure 3.1).). The blocks were allowed to simmer for about 5 minutes in the solution; very hardwoods required rather longer period when softer ones required a shorter period. Care was taken to avoid maceration as a result of keeping the wood too long in the mixture. The idea in using the reflex condenser was to prevent the evaporation of the mixture, which might irritate the respiratory tissues as well as that saving the softening solution. The softened blocks were picked out of the flask and washed several time in running water before sectioning.



Sectioning:

Serial sections of each cross (transverse) section and longitudinal section 10-15 μm were cut from each set of tree stem/ branches, the blocks of wood were sectioned by a sliding microtome (Figure 3.2), it is sometime recommended that for the cutting of transverse sections, the rays should be parallel to the direction of movement of the knife in cutting section. Both the block and the knife should be flooded with 70% alcohol. The sections were then transferred to glass slide and covered with another slide. Dehydration by applying four drops of three concentrations of ethyl alcohol 25% - 50% and absolute respectively, to the sections while they were laid up on the slides surface. Each concentration was left for approximately one minute, then dropped away to be replaced by a higher concentration. The sections were then ready for staining.



Figure 3.2. Slide microtome used for sectioning.

Staining

The sections then transferred into a Petri dish, half filled with xylene, and the sections were ready for mounting. The three concentrations of alcohol used to allow gradual dehydration of sections, and to wash the excess amount of the stain. The xylene used for cleaning, fixing the dye and making it bright. The stained sections were released from the slides surface, washed in several times in distilled water in Petri dish, soaked in 25% -50% and

absolute ethyl alcohol. The sections stained with safranine, left for 2 hours, and then washed in a series of ethanol (50% - 75% and 100 percentages). For 5 minutes in each concentration, the sections were then dried of the ethanol and washed with xylene and the sections were ready for mounting.

Mounting

After staining and washing the transverse sections were transferred and placed on a clean (three by one inch) glass. Slide two or three drops of Canada balsam were dropped on the section, and then covered with a slip of appropriate size (18 x18 mm). The pressing had to be towards the cover slip margin to push the air bubbles that can be trapped under the cover slip marginal to push the air bubbles that can be trap red underneath the cover slip. The slides were put on a flat surface until air bubbles disappeared. The slides were left lying flat for several days until the balsam becomes quite hard. The preparations were completed at this stage by cleaning away surplus balsam with a cloth dipped in xylene. The enstereological counts were then carried out on these sections.

3.2.3. Anatomical Examination

The microscopic examination included the main two parts, namely qualitative and quantitative, to describe the micro-structure of wood under the microscope.

This qualitative examination included the distribution and arrangement of wood vessels and parenchyma cells, and the description of wood fiber and wood rays. Also the macro-structures of wood and charcoal were studied by the hand lens. The quantitative examination included volume fractions, number of cells/mm² and some measurements of the vessel elements, fibers, longitudinal parenchyma and rays beside the volume fraction of wood substance.

For all species 120 slides were used and five fields from each slide were examined. Seventy five fields under the microscope were studied for each tree species (5 trees x 3 billets x 1 slide x 5 fields). The quantitative data was obtained following the procedure of stereological counting described by Ifju *et al.*,(1978) and Nasroun. (1987). Various stereological equations were applied according to Nasroun. (1978); Nasroun. 1987; Nasroun. 2005).

There were magered the rays qualitively by naked eyes and hand lens was obtained flowing:-

-When ray can be seen Cleary by the naked eye which out lens we say large (broad) rays.

-When they cannot be seen Cleary by the naked eye but can be seen clearly by the lens we say moderately (medium) broad rays.

-When they cannot be seen Cleary (hardly seen) by the naked eye or with the lens we say very small rays or narrow rays.

3.2.4. Stereological Method of Measurement

Stereological count was conducted following the procedure of (Ifju *et al*, 1978). Two grids Were used for measurement; one was a nine-point square grid 12x12 cm, and the other was a sixteen point square grid 12x12 cm in dimension. Each of two grids was drawn on a transparent paper, and then was fixed on a computer screen (monitor). The glass slide was fixed on the slide theater of the light microscope. The picture on the microscope was projected onto the computer monitor through the camera using a 10X objective piece (Figure 3.5). A glass micro scale was projected onto the monitor to find the magnification used and then find the length of test lines and total test area. The magnification was 60X

$$\text{One test line} = \frac{120}{60}$$

$$\text{Test line} = 2\text{mm.}$$

- In a nine-point square grid 12x12 cm,

$$\text{Total test line} = 2 \times 3 = 6\text{mm.}$$

$$\text{Total test area} = 2^2 = 4\text{mm}^2$$

- In a sixteen point square grid 12x12 cm

$$\text{Total test line} = 2 \times 4 = 8\text{mm.}$$

$$\text{Total test area} = 2^2 = 4\text{mm}^2$$



Figure 3.5. The grid, computer and camera using for Stereological count.

Using the wood cross-sections, the point fraction (P_{pc}), the number of points of intersection with boundaries of cells generated per unit length of test lines (PL) and the number of objects or features or cells per unit area of the microstructure (NA) were obtained for vessels, rays, parenchyma and fibers and their components. The data were entered in the computer and calculations were made using the following equations:

Volume fraction of vessel, fiber, parenchyma, rays and their components were determined as given in Equations 3.1 to 3.7.

$$P_{pc} = P_{pw} + P_{pl} \quad \text{Eq. 3.1}$$

Where:

P_{pc} = the point (volume) fraction of the cell type.

(Vessel, fiber, parenchyma and rays).

P_{pw} = the point (volume) fraction of the cell walls.

P_{pl} = point (volume) fraction of the cell lumens.

$$CWF = P_{pwV} + P_{pwF} + P_{pwP} + P_{pwR}. \quad \text{Eq. 3.2}$$

Where:

CWF = Cell-wall volume fraction of vessel, Fiber, Parenchyma and Rays.

P_{pwV} = the point (volume) fraction of the vessels cell wall.

PpwF = the point (volume) fraction of the fibers cell wall.

PpwP = the point (volume) fraction of the parenchyma cell wall.

PpwR. = the point (volume) fraction of the rays cell wall.

$$D_{(h)} = \frac{PL_{(h)}}{2NA} \quad \text{Eq. 3.3}$$

Where:

$D_{(h)}$ = Horizontal diameter of vessel, fiber and parenchyma.

$PL_{(h)}$ = the number of intersection points of the four or three horizontal lines of the test grid with cell boundaries per unit length.

NA = the total number of vessels per unit test area.

$$D_{(v)} = \frac{PL_{(v)}}{2NA} \quad \text{Eq. 3.4}$$

Where:

$D_{(v)}$ = vertical diameter of vessel, fiber and parenchyma.

$PL_{(v)}$ = the number of intersection points of the four or three Vertical lines of test grid with cell boundaries per unit test line.

$$VD_{(lum)} = \sqrt{\frac{4Pp_{(lum)}}{\pi NA}} \quad \text{Eq. 3.5}$$

Where:

LD = cells lumen diameter.

$Pp_{(lum)}$ = volume fraction of cell lumen.

NA = the number of cells per unit area of microstructure.

$$DCWT = D - LD \quad \text{Eq. 3.6}$$

Where:

DCWT = Double cell wall thickness.

D = cell diameter.

LD cell lumen diameter.

$$\text{MFP} = \frac{2(1 - P_p)}{P_L} \quad \text{Eq.3.7}$$

Where:

MFP = mean free path between Cells.

P_p = the number of test points on a particular feature per unit test point.

P_L = the number of points of intersection with cell boundaries generated per unit length of test lines.

3.2.5. Carbonization Method

The other parts of the billets were used for charcoal production in a traditional earth mound kiln to produce charcoal by burning the wood under oxygen-depleted conditions. This traditional system which requires no more equipment to operate than axe, shovel, rake and matches, is still widely used especially by subsistence producers.

A pile of wood in the form of flattened hemisphere on a grid of cross logs, to allow air circulation, was built on a cleared area. The pile was covered with grass followed by a layer of sand or sandy loam to a thickness of about 11-12 cm. A series of air holes were opened around the base, and an opening on the top was left for lighting and for the escape of smoke. The mound was lit by placing a shovel of burning charcoals in the top opening. Dry wood was placed at the top of the pile to enable the fire to take hold easily.

Combustion spreads slowly through the pile and after a few days the smoke became quite clear. All the openings were then sealed. During burning, the operator attempted to direct the progress of the fire front so that it progresses symmetrically through the pile. A watch was kept for cracks and air leaks and they were quickly plugged with sand or earth. After two weeks the pile was opened with a rake, which was used to separate the charcoal from the sand earth (Booth, 1983) and the mound was allowed to cool.

A fresh, transverse surface of charcoal was obtained by breaking a piece of modern charcoal by hand, and then cleaned gently with air. The sample was then observed by moving the hand lens up and down, until it was possible to get a focused view of the charcoal surface to enable its description.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Wood and Charcoal Anatomical Description

In the following sections the anatomical description of the wood and charcoal are given separately for each species.

4.1.1. *Acacia senegal* (Linn.) var. *senegal* Brenan (hashab)

Wood Micro-Structure

Wood is diffuse porous.

Vessels arrangement: Solitary, clusters and in radial multiples of 2-3; occasionally in tangential multiples (Figure 4.1) Perforation plate simple. Vessel wall pitting scalariform patterns, wall thickening absent. Gum deposits present and tyloses absent. and (Table 4.1).

Vessels element diameter horizontal 0.097 mm, vertical 0.103 mm. Double-cell wall thickness horizontal 0.009 mm, vertical 0.003 mm. Vessels lumen diameter 0.106 mm. Vessels mean free path horizontal 0.62 mm, vertical 0.59 mm. Number of vessel per mm² 13.59. Vessels volume fraction 18% in (Table 4.2).

Fiber: Thick-walled non-septate, crystals present; horizontal and vertical diameter 0.016 mm and 0.017 mm respectively. Fiber lumen diameter 0.013 mm. Double-cell wall thickness horizontal 0.004 mm, and vertical 0.003 mm. Number of fiber per mm² 1495.04. Fiber volume fraction 38%(Table 4.3).

Parenchyma: Confluent and banded Paratracheal dominant, occasionally aliform and aliform-confluent. Figure (4.1). Crystals present. (Table 4.4).

Horizontal and vertical diameter 0.017 mm and 0.018 mm respectively, lumen diameter 0.013 mm, double-cell wall thickness horizontal 0.005 mm and vertical 0.004 mm. Number of Parenchyma per mm² 974.09. Parenchyma volume fraction 25%.(Table 4.5).

Rays: Homogenous, long rays, triseriate, diseriata dominant, rarely multiseriate. Gum deposits and crystals present. Number of rays per mm² 8.70. Rays volume fraction 20%. (Table 4.6).

Wood substance: Occupies 44 %.

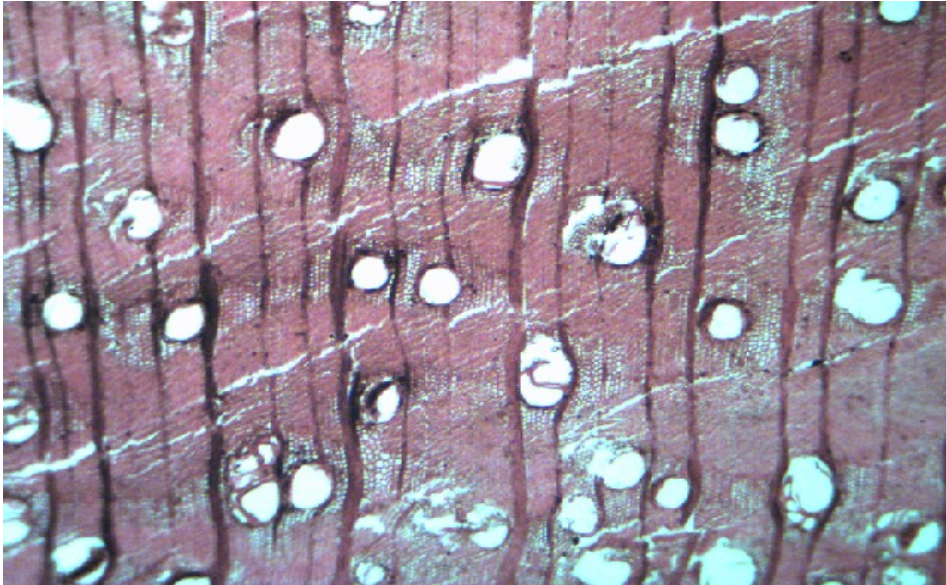


Figure 4.1 *Acacia senegal* cross-section

These results confirm the results of Osman (2000) that in both juvenile and mature gum deposits were found in vessels and ray and crystals were found in fiber, longitudinal parenchyma and ray. The volume fraction of vessels, fibers and rays found in this study was larger and the volume fraction of parenchyma was smaller than the values given by Osman (2000).

The vessel wall volume fraction in this study was larger than the values of mature wood, but smaller than the values of juvenile wood found by Osman (2000), while the fiber wall volume fraction found in this study was larger than wall volume fraction of juvenile wood and smaller than wall volume fraction of mature wood was given by Osman (2000) while ray wall volume fraction found in this study was smaller than mature wood and juvenile wood wall volume fraction given by Osman(2000), the fiber and parenchyma lumen volume fractions found in this study were larger than the juvenile wood lumen volume fractions and smaller than the mature wood lumen volume fraction found by Osman (2000).

Wood Macro-Structure

Growth rings usually more distinct by naked eye or lens. Vessels look like spots, dominant solitary occasionally tangential arrangement. Fibers are

seen thick banded. Parenchyma confluent, aliform and in broad banded. Rays broad as bright parallel lines.

Charcoal Macro-Structure

Growth rings usually distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution just solitary. Fiber not distinct by naked eye or lens Parenchyma banded. Rays are seen as shiny and clearly as narrow discontinuous lines.

4.1.2. *Acacia nilotica* (Linn.) Willd. ex Del. (Sunt)

Wood Micro-Structure

Wood is diffuse – porous.

Vessels: Solitary, radial multiples of 2-3 cells dominant occasionally clustered. (Figure 4.2). Perforation plate simple. Vessels wall pitting scalariform patterns, wall thickening absent. (Table 4.1).

Gum deposits present and tyloses absent. Vessels element diameter horizontal 0.13 mm, vertical 0.12 mm. Double-cell wall thickness horizontal 0.03mm, vertical 0.02 mm. Vessels lumen diameter 0.10 mm. Vessels mean free path horizontal 0.21 mm, vertical 0.23 mm. Number of vessel per mm² 28.54. Vessels volume fraction 19%.(Table 4.2).

Fiber: Thick wall, non septate, crystals present. Horizontal and vertical diameter 0.017 mm and 0.018 mm respectively. Fiber lumen diameter 0.014 mm. Double-cell wall thickness horizontal 0.003 mm and vertical 0.004 mm. Number of fiber per mm² 1486.96. Fiber volume fraction 33%.(Table 4.3).

Parenchyma: Aliform, confluent and vasicentric.(Figure 4.2). Crystals present. (Table 4.4).

Horizontal and vertical diameter 0.020 mm and 0.019 mm respectively. Lumen diameter 0.011 mm. Double-cell wall thickness horizontal 0.009 mm and vertical 0.008 mm. Number of Parenchyma per mm² 1487.22. Parenchyma volume fraction 25%.(Table 4.5).

Rays: Homogenous, multiseriate, triseriate dominant, occasionally uniseriate and diseriata. Number of rays per mm² 30.17. Rays proportion 23%.(Table 4.6).

Wood substance: Occupies 39%.

These results confirm the results of Osman (2000) that in both juvenile and mature wood gum deposits were found in vessels and crystals were found in fiber and longitudinal parenchyma. However, the volume fraction of vessels and rays found in this study was larger and the volume fraction of fiber was smaller than the values given by Osman (2000)

The fiber diameter found in this study confirm the results of Osman (2000) that in both juvenile wood and mature wood, and vessels, longitudinal parenchyma and ray diameter was smaller than the values given by Osman (2000).

Vessels and longitudinal parenchyma wall and lumen volume fraction in this study were larger and fiber wall and lumen volume fraction were found in this study were smaller than the values of mature wood and juvenile wood found by Osman (2000).

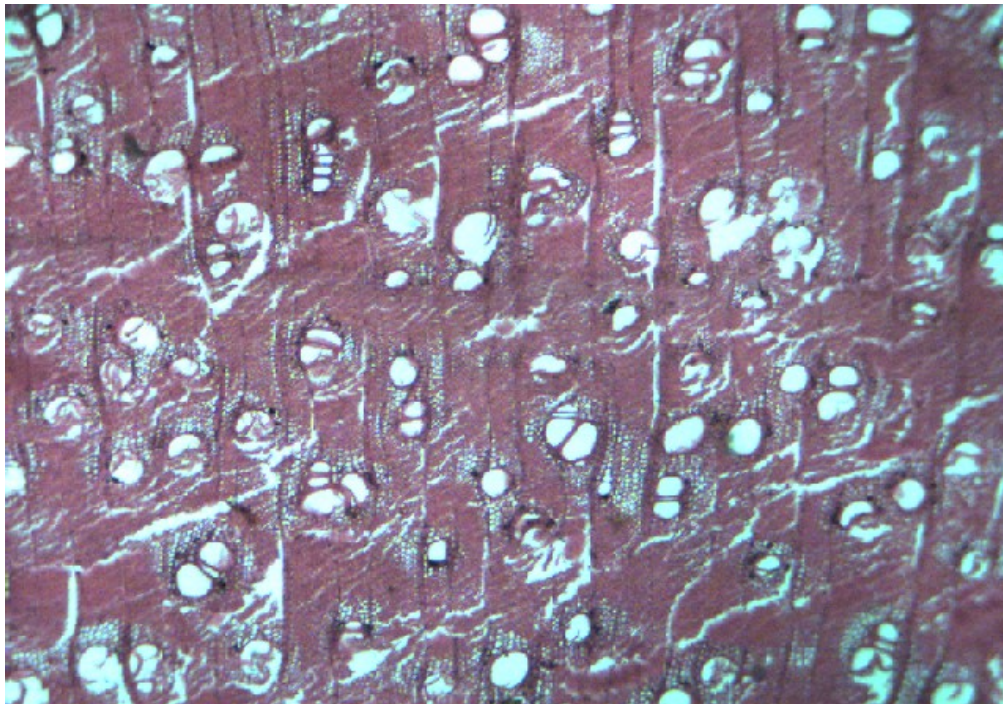


Figure 4.2 *Acacia nilotica* cross-section

Wood Macro-Structure

Growth rings usually not distinct by naked eye or lens (what appears as narrow growth rings is actually paratracheal confluent to banded). Vessels look like spots, dominant radial multiples, occasionally solitary. Fibers are seen as red thick banded. Parenchyma dominant vasicentric, occasionally aliform. Rays broad, as bright parallel lines.

Charcoal Macro-Structure

Growth rings usually more distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution just solitary. Fiber not distinct by naked eye or lens. Parenchyma not distinct by naked eye or lens. Rays are seen as shiny and clearly as narrow discontinuous lines.

4.1.3. *Acaci seyal* Del. Var. *seyal* Brenan (Taleh)

Wood Micro-Structure

Wood is diffuse porous.

Vessels: Solitary, radial multiples of 2-4 cells, cluster, oblique multiples oblique arrangement of 2 cells, rarely tangential multiples of 2-3 cells (Figure 4.3). Perforation plate simple. Vessels wall pitting alternate, wall thickening absent. Gum deposits present and tyloses absent. (Table 4.1).

Vessels element diameter horizontal 0.08 mm, vertical 0.23 mm. Double-cell wall thickness horizontal 0.01 mm, vertical 0.16 mm. Vessels lumen diameter 0.07 mm. Vessels mean free path horizontal 0.403 mm, vertical 0.4 mm. Number of vessel per mm² 23.30. Vessels volume fraction 18%. (Table 4.2).

Fiber: Thick wall, non septate, crystals present. Horizontal and vertical diameter 0.13 mm and 0.13 mm respectively. Fiber lumen diameter 0.031 mm. Double-cell wall thickness horizontal 0.1 mm, and vertical 0.1 mm. Number of fiber per mm² 188.78. Fiber volume fraction 37%. (Table 4.3).

Parenchyma: confluent, occasionally aliform confluent, aliform (Figure 4.3). Gum deposited and Crystals present. (Table 4.4).

Horizontal and Vertical diameter 0.16 mm and 0.15 mm respectively. Lumen diameter 0.04 mm. Double-cell wall thickness horizontal 0.12 mm and vertical 0.11 mm. Number of Parenchyma per mm² 1060.7. Parenchyma volume fraction 23%.(Table 4.6).

Rays: Homogenous, multiseriate and crystals present.

Number of rays per mm² 10.70. Rays proportion 21%.(Table 4.6).

Wood substance: occupies 41%.

These results confirm the results of Osman (2000) that in both juvenile and mature wood gum deposits were found in vessels and longitudinal parenchyma and crystals were found in fiber

The volume fraction of vessels and fibers found in this study was larger, and the volume fraction of longitudinal parenchyma was smaller than the values given by Osman (2000).The diameter of vessels, fiber and parenchyma found in this study were smaller than the values given by Osman (2000).

The vessel walls and lumen volume fraction in this study were larger and ray wall and lumen volume fraction were smaller than the values of mature wood and juvenile wood found by Osman (2000), while the fiber wall volume fraction was found in this study was larger than wall volume fraction juvenile wood and smaller than wall volume fraction of mature wood given by Osman (2000). However longitudinal parenchyma wall volume fraction found in this study was smaller, than the values of mature wood and juvenile wood found by Osman (2000).

Fiber lumen volume fraction was found in this study was larger than lumen volume fraction mature wood and juvenile wood were found in Osman (2000), but longitudinal parenchyma lumen volume fraction was found in this study was larger than lumen volume fraction of mature wood and smaller than lumen volume fraction juvenile wood given by Osman (2000)

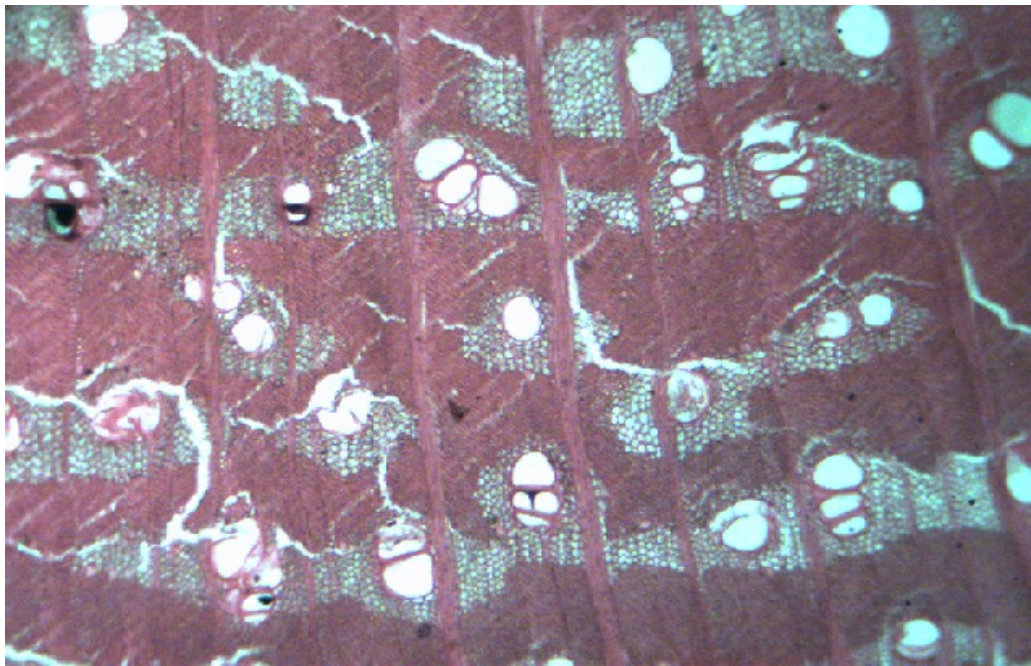


Figure 4.3 *Acacia seyal* cross-section

Wood Macro-Structure

Growth rings usually more distinct by naked eye or lens. Vessels look like spots, dominant radial multiples, tangential multiple, occasionally solitary, clustered. Fibers are seen as thick bands. Parenchyma dominant confluent, occasionally aliform rarely vasicentric. Rays narrow.

Charcoal Macro-Structure

Growth rings usually not distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution just solitary. Fiber not distinct by naked eye or lens. Parenchyma vasicentric. Rays are seen as shiny and clearly as broad lines.

4.1.4. *Prosopis chilensis* (Mol.) Stuntz (Mesquite)

Wood Micro-Structure

Wood is diffuse porous

Vessels: Solitary, radial multiples of 2 cells, oblique multiples, clusters, (Figure 4.4). Perforation plate simple. Vessels wall pitting alternate, spirals thickening absent. Gum deposits present and tyloses absent. (Table 4.1).

Horizontal Vessels element diameter 0.102 mm, vertical 0.094 mm. Double-cell wall thickness horizontal 0.009 mm, vertical 0.001 mm. Vessels lumen diameter 0.093 mm. Vessels mean free path horizontal 0.70 mm, vertical 0.76 mm. Number of vessel per mm² 11.86 Vessels volume fraction 15%.(Table 4.2).

Fiber: Thick-walled non-septate. Gum deposits present. Vertical and horizontal diameter 0.019 mm and 0.018 mm respectively. Fiber lumen diameter 0.014 mm. Double-cell wall thickness horizontal 0.005 mm, and vertical 0.004 mm. Number of fiber per mm² 1414.17. Fiber volume fraction 34%.(Table 4.3).

Parenchyma: banded paratracheal dominant, occasionally confluent, aliform (Figure 4.4); (Table 4.4).

Vertical and horizontal diameter 0.017 mm and 0.017 mm respectively. Lumen diameter 0.011 mm. Double-cell wall thickness horizontal 0.006 mm and vertical 0.006 mm. Number of Parenchyma per mm² 1257.65. Parenchyma volume fraction 26%.(Table 4.5).

Rays: Homogenous, triseriate, dieseriate, occasionally uniseriate. Number of rays per mm² 13.10. Rays volume fraction 26%.(Table 4.6).

Wood substance: Occupies 43 %.

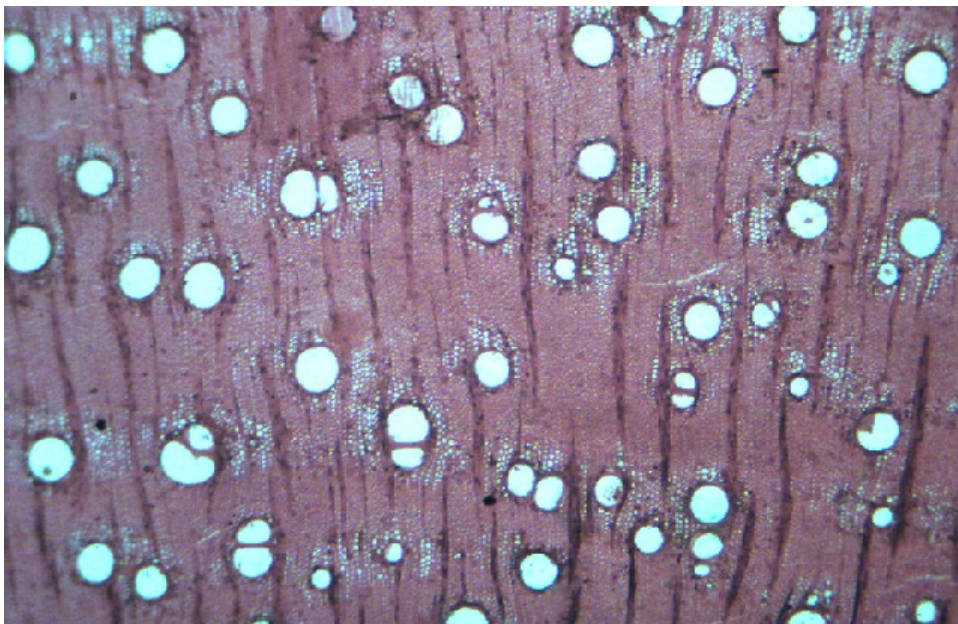


Figure 4.4 *Prosopis chilensis* cross-section

Wood Macro-Structure

Growth rings usually not distinct with naked eye or lens (what appears as narrow growth rings is actually paratracheal confluent to banded). Vessels look like spots, dominant oblique, solitary, occasionally radial multiple, tangential multiple and cluster. Fibers are seen thick banded. Parenchyma dominant confluent banded occasionally aliform. Rays modality broad and as bright parallel lines.

Charcoal Macro-Structure

Growth rings not distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution just solitary. Fibers not distinct by naked eye or lens. Parenchyma banded Rays are seen as shiny and clearly as narrow lines.

4.1.5. *Acacia mellifera* (Vahl) Benth.(Kitr).

Wood Micro-Structure

Wood is diffuse porous

Vessels: Solitary dominant, clusters, radial multiples of 2-3 cells (Figure 4.5). Perforation plate simple. Vessels wall pitting scalariform patterns helical thickening absent. Gum deposits present and tyloses absent. (Table 4.1).

Vessels element diameter horizontal 0.117 mm, vertical 0.116 mm. Double-cell wall thickness horizontal 0.002 mm, vertical 0.001 mm. Vessels lumen diameter 0.115 mm. Vessels mean free path horizontal 0.79 mm, vertical 0.80 mm. Number of vessel per mm² 9.48 Vessels volume fraction 16%.(Table 4.2).

Fiber: Thick-walled non-septate, gum deposits and crystal present. Horizontal and vertical diameter 0.016 mm and 0.019 mm respectively. Fiber lumen diameter 0.013 mm. Double-cell wall thickness horizontal 0.003 mm, and vertical 0.06 mm. Number of fiber per mm² 2255.48. Fiber volume fraction 47%.(Table 4.3).

Parenchyma: banded paratracheal dominant, occasionally confluent, aliform (Figure 4.5); (Table 4.4). Horizontal and vertical diameter 0.020 mm and

0.020 mm respectively. Lumen diameter 0.014 mm. Double-cell wall thickness horizontal 0.006 mm and vertical 0.006 mm. Number of Parenchyma per mm² 693.39. Parenchyma volume fraction 18%.(Table 4.5).

Rays: Homogenous, triseriate dominant, dieseriate, multiseriate. Number of rays per mm² 7.16. Rays volume fraction 19%. (Table 4.6).

Wood substance: Occupies 39%.

These results confirm the results of Osman (2000) that in both juvenile and mature wood gum deposits were found in vessels and crystals were found in fibers.

The volume fractions of vessels and rays found in this study were larger and the volume fractions of fiber and longitudinal parenchyma were smaller than the values given by Osman (2000). The diameter of vessels and fibers found in this study was smaller than the values given by Osman (2000).

The vessels and longitudinal parenchyma wall volume fraction in this study were smaller than the values of mature wood found by Osman (2000), but vessels and ray wall volume fraction in this study were larger than wall volume fraction juvenile wood given by Osman (2000), while the fiber wall volume fraction was found in this study was smaller than wall volume fraction mature wood and juvenile wood given by Osman (2000).

Vessels lumen volume fraction was found in this study was larger than lumen volume fraction of juvenile wood given by Osman (2000), but longitudinal parenchyma lumen volume fraction found in this study was larger than lumen volume fraction of mature wood given by Osman (2000). Fiber and ray lumen volume fractions, on the other hand, found in this study were larger than the values of juvenile wood and mature wood given by Osman (2000).

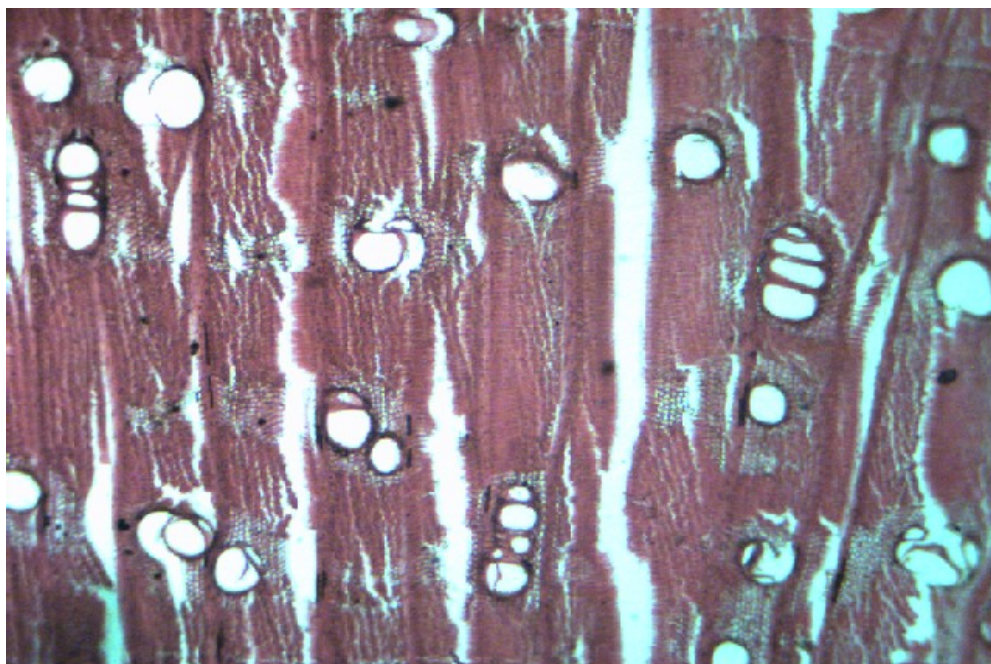


Figure 4.5 *Acacia mellifera* cross-section

Wood Macro-Structure

Growth rings more distinct by naked eye or lens. Vessels look like spots, dominant solitary, oblique dominant, occasionally radial multiple and clustered. Fibers are seen thick banded. Parenchyma aliform, confluent, and vasicentric. Rays medium broad as bright parallel lines.

Charcoal Macro-Structure

Growth rings more distinct by lens. Vessels look like darker spots, but not much can be seen of their shape or distribution, solitary, radial multiple and tangential multiple. Fiber not distinct by naked eye or lens. Parenchyma vasicentric. Rays are seen as shiny and clearly as narrow lines.

4.1.6. *Eucalyptus camaldulensis* Dehn.(Ban or Kafur)

Wood Micro-Structure

Wood is diffuse– porous.

Vessel: solitary dominant, oblique arrangement, tangential multiples of 2 cells, radial multiples of 2 cells, clusters (Figure 4.6)

Perforation plate simple. Vessels wall pitting alternate. Gum deposits present and tyloses absent. (Table 4.1).

Vessel element diameter horizontal 0.11 mm, vertical 0.13 mm. Double-cell wall thickness horizontal 0.03 mm, vertical 0.05 mm. Vessels lumen diameter 0.08 mm. Vessels mean free path horizontal 0.28 mm, vertical 0.34 mm. Number of vessel per mm² 29.57. Vessels volume fraction 25%.(Table 4.2).

Fiber: Thick wall, non septets. Horizontal and vertical diameter 0.07 mm and 0.06 mm respectively. Fiber lumen diameter 0.05 mm. Double-cell wall thickness horizontal 0.02 mm, and vertical 0.01 mm. Number of fiber per mm² 137.07 Fiber volume fraction 27%.(Table 4.3).

Parenchyma: diffuse (Figure 4.6); (Table 4.4). Horizontal and vertical diameter 0.19 mm and 0.16 mm respectively. Lumen diameter 0.04 mm. Double-cell wall thickness horizontal 0.15 mm and vertical 0.12 mm. Number of Parenchyma per mm 104.14. Parenchyma volume fraction 21%.(Table 4.5).

Rays: Homogenous, rays very thin, characteristics uniseriate dominant, diseriata, triseriate occasionally. Gum deposits present.

Number of rays per mm² 21.65. Rays volume fraction 27%. (Table 4.6).

Wood substance: Occupies 30%.

Wood Macro-Structure

Growth rings distinct by naked eye or lens. Vessels look like spots, small size, dominantly oblique arrangement, solitary. Fibers are seen as red thick bands. Parenchyma not distinct by naked eye or lens. Rays very narrow and difficult to distinguish by naked eye or lens.

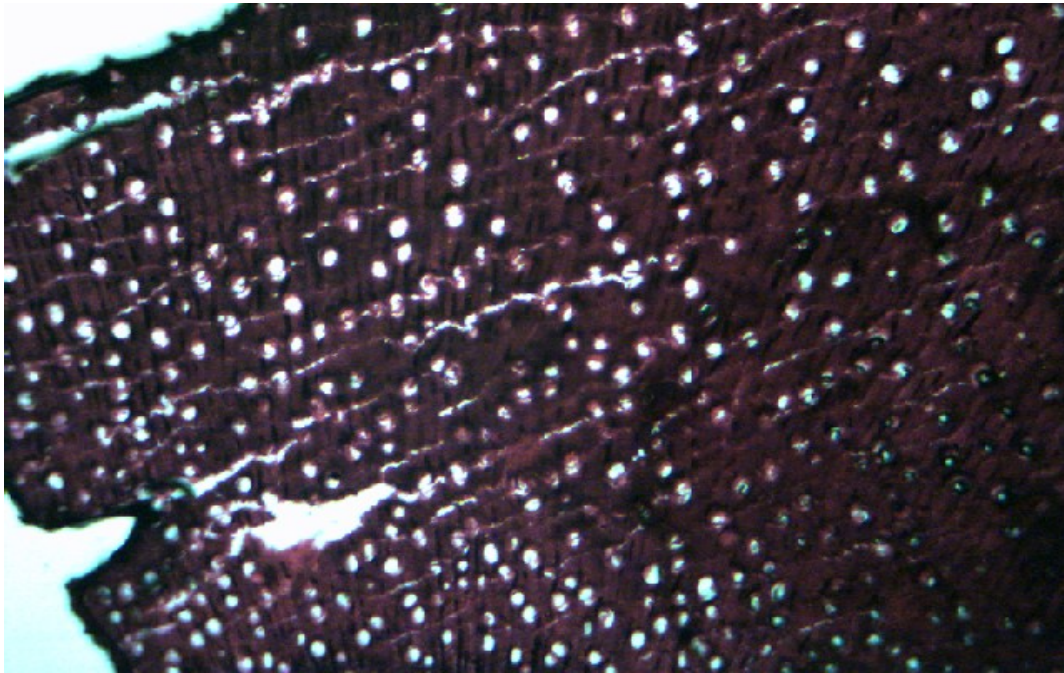


Figure 4.6 *Eucalyptus camaldulensis* cross-section

Charcoal Macro-Structure

Growth rings not distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution, cluster. Fiber not distinct by naked eye or lens. Parenchyma not distinct by naked eye or lens. Rays are seen as shiny and clearly as narrow discontinuous lines.

4.1.7. *Balanites aegyptiaca* (Linn.) Del. (Heglig)

Wood Micro-Structure

Wood issemi ring – porous

Vessels: Solitary, radial multiples arrangement, oblique multiples arrangement, tangential multiples arrangement (Figure 4.7).

Perforation plate simple. Vessels wall pitting alternate. Gum deposits and tyloses were absent. (Table 4.1).

Vessels element diameter horizontal 0.083 mm, vertical 0.068 mm. Double-cell wall thickness horizontal 0.027 mm, vertical 0.012 mm. Vessels lumen diameter 0.056 mm. Vessels mean free path horizontal 0.693 mm, vertical 0.844 mm. Number of vessel per mm² 15.57. Vessels volume fraction 11 %. (Table 4.2).

Fiber: Thick wall, non septate. Horizontal and vertical diameter 0.017 mm and 0.018 mm respectively. Fiber lumen diameter 0.014 mm. Double-cell wall thickness horizontal 0.003 mm, and vertical 0.004 mm. Number of fiber per mm² 1280.96 Fiber volume fraction 31%.(Table 4.3).

Parenchyma: apotracheal parenchyma, diffuse in aggregate and banded.(Figure 4.7); (Table 4.4).

Horizontal and vertical diameter 0.019 mm and 0.019 mm respectively. Lumen diameter 0.013 mm. Double-cell wall thickness horizontal 0.006 mm and vertical 0.006 mm. Number of Parenchyma per mm² 1125.39 Parenchyma volume fraction 31%.(Table 4.5).

Rays: Homogenous, rays very big (huge), characteristics very broad multiseriate, Gum deposits present.

Number of rays per mm² 5.01. Rays volume fraction 26%. (Table 4.6).

Wood substance: Occupies 40%.

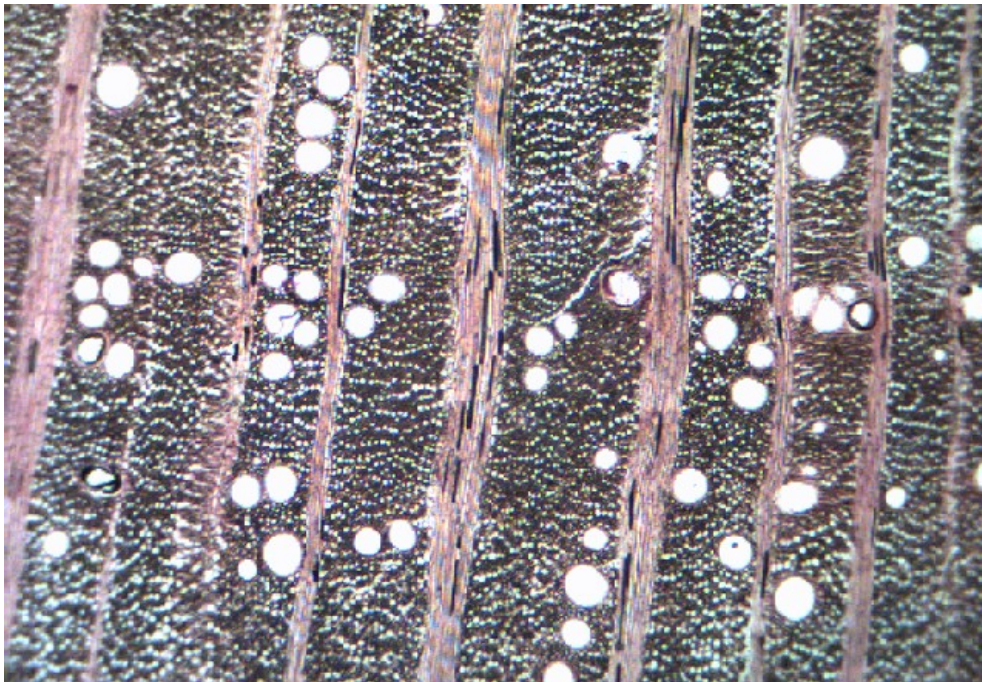


Figure 4.7 *Balanites egyptiaca* cross-section

Wood Macro-Structure

Growth rings are distinct to the extent that they can be seen with naked eye. Vessels look like spots, dominantly in clusters, occasionally solitary and in

radial arrangement. Fibers are seen as red thick banded. Parenchyma dominantly banded occasionally vasicentric. Rays very broad.

Charcoal Macro-Structure

Growth rings not distinct by naked eye or lens. Vessels look like dark spots, but not much can be seen of their shape or distribution, solitary and radial arrangement. Fiber no distinct by naked eye or lens. Parenchyma not distinct by naked eye or lens. Rays are seen as shiny and clearly as broad.

4.1.8. *Anogeissus leiocarpus* (DC.) Guill and Perr (Sahab)

Wood Micro-structure

Wood is semi ring – porous

Vessels: Radial multiples of 2-5 cells dominant, occasionally clusters (Figure 4.8). Perforation plate simple. Vessels wall pitting alternate, wall thickening absent. Gum deposits present and tyloses absent. (Table 4.1).

Vessels element diameter horizontal 0.21 mm, vertical 0.22 mm. Double-cell wall thickness horizontal 0.02 mm, vertical 0.03mm. Vessels lumen diameter 0.19 mm. Vessels mean free path horizontal 0.01 mm, vertical 0.09 mm. Number of vessel per mm² 35.30 Vessels volume fraction 22%.(Table 4.2).

Fiber: Thick wall, non septate. Gum deposits present. Horizontal and vertical diameter 0.014 mm and 0.014 mm respectively. Fiber lumen diameter 0.011 mm. Double-cell wall thickness horizontal 0.003 mm, and vertical 0.003 mm. Number of fiber per mm² 1722.26 Fiber volume fraction 24%.(Table 4.3).

Parenchyma: Apotracheal parenchyma, diffuse, vasicentric. (Table 4.4). Horizontal and vertical diameter 0.014 mm and 0.015 mm respectively. Lumen diameter 0.011 mm. Double-cell wall thickness horizontal 0.003 mm and vertical 0.004 mm. Number of Parenchyma per mm² 1010.61 Parenchyma volume fraction 17%.(Table 4.5).

Rays: Heterogonous, rays very thin, uniseriate. Gum deposits present.

Number of rays per mm² 34.75. Rays volume fraction 29%. (Table 4.6).

Wood substance: Occupies 39%.

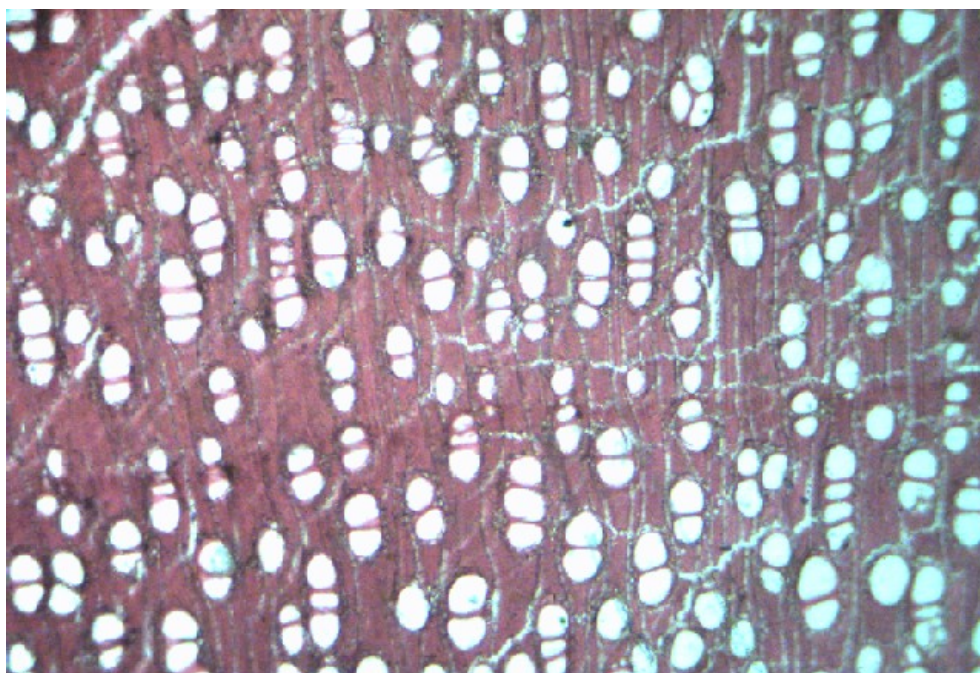


Figure 4.8 *Anogeissus leiocarpus* cross-section

Wood Macro-Structure

Growth rings usually not distinct by naked eye or lens (what appears as narrow growth rings is axially paratracheal confluent to banded parenchyma). Vessels look like spots, dominant radial multiple, occasionally cluster. Fibers are seen red thick banded. Parenchyma vasicentric. Rays difficult to distinct by naked eye or lens.

Charcoal Macro-Structure

Growth rings usually more distinct by naked eye or lens. Vessels look like darker spots, but not much can be seen of their shape or distribution, solitary and radial arrangement. Fiber not distinct by naked eye or lens. Parenchyma not distinct by naked eye or lens. Rays not distinct by naked eye or hand lens.

4.2. Variation in Wood Micro -Structure among Species

4.2.1. Qualitative

The variation in the anatomical features between the studied species is summarized in Table 4.1. These species showed little variation in wood

porosity. The vessel distribution in all of these species was diffusing porous, except in *B. aegyptiaca* and *A. leiocarpus*, which were semi-ring porous.

Inter vessels pitting was dominantly alternate polygonal, linear to oval, but slightly reticulate to half scalariform patterns were present in three of the three studied *Acacias*, namely, *A. nilotica*, *A. mellifera* and *A. senegal*. All of the studied species had simple vessel perforation plate and tyloses were not present.

The arrangement (type) of vessels was predominately solitary in all of the species except *A. leiocarpus*. Also radial multiples and cluster vessels were present in all studied species. Oblique vessel arrangement was present in *E. camaldulensis* only. Oblique multiples observed in *A. seyal*, *A. mellifera*, *B.aegyptiaca* and *P. chilensis*. Tangential multiple vessels were present in *A.senegal*, *A. seyal*, *B. aegyptiaca* and *E. camaldulensis*, but absent in the other species.

Gum materials in vessels had been observed in all of the species except *B.aegyptiaca*. In fibers, gum deposits were present in *P. chilensis*, *A. mellifera* and *A. leiocarpus*. Gum material in parenchyma was observed only in *Acacia. seyal*. Gum material was also present in ray parenchyma in *A. senegal*, *E. camaldulensis*, *B. aegyptiaca* and *A. leiocarpus*.

Crystals in parenchyma were present only in acacia species, namely, *A senegal*, *A. seyal* and *A nilotica*. Also crystal material in fiber was found in *A senegal*, *A. seyal* and *A. nilotica*, while crystal in ray was found only in *A. senegal* and *A. seyal*

All species under study had homogenous rays except *A. leiocarpus* had heterogeneous ray. Uniseriate rays were dominantly present in *E. camaldulensis* and *A. leiocarpus* and was occasionally present in *A. nilotica* and *P. chilensis*. Diseriate rays were dominantly present in *A. senegal*, and *P. chilensis*, and occasionally in *A. mellifera*, *E. camaldulensis* and *A. nilotica*. Triseriate rays were dominantly present in *A. senegal*, *A. nilotica*, *A. mellifera* and, *P. chilensis*,. while multiseriate ray was dominantly present in *A. nilotica*, *B.aegyptiaca* and *A. seyal* and was present occasionally only in *A. Senegal* and *A. mellifera*.

4.2.2. Quantitative

The studied species showed similarities and variations in the quantitative characteristics. Species mean values of these characteristics are grouped in Tables 4.2, 4.3, 4-4, 4.5 and 4.6 for the vessels, fibers, longitudinal parenchyma and rays, respectively. There were small variations between the studied species in the vertical and horizontal cell diameter, lumen diameter and double cell-wall thickness of the vessel, fiber and parenchyma.

Greater variations were observed in vessels number per mm², which ranged between 9.48 in *A. mellifera* and 35.30 in *A. leiocarpus*, and in vessels volume fraction, which varied from 11% in *B. aegyptiaca* to 25% in *E. camaldulensis*. Also, there were great variations in volume fractions of fibers between 24% in *A. leiocarpus* and 38% in *A. senegal*, and in fiber number per mm², which ranged between about 137.07 per mm² in *E. camaldulensis* and 2255.48 per mm² in *A. mellifera*.

Great variations were also noted in the number of parenchyma per mm² and parenchyma volume fraction. The number of parenchyma cells per mm² of the studied species ranged between 104.14 in *E. camaldulensis* and 1487.32 in *A. nilotica*. However, the lowest parenchyma volume fraction (17%) was found in *A. leiocarpus* and the highest fraction (31%) was found in *B. aegyptiaca*. The highest volume fraction and number of rays per mm² was obtained by *A. leiocarpus* (29% and 34.75 mm², respectively), while the lowest values were obtained by *A. mellifera* (19% and 7.16/mm², respectively). The wood substance showed considerable variation among species with a range from 30% in *E. camaldulensis* to 44% in *A. senegal*.

4.3. Variation in Wood Macro-Structure among Species

Growth rings were clearly seen in all of the studied species except *P. chilensis*, *A. nilotica* and *A. leiocarpus*.

Solitary vessels were present in all studied species, but radial multiple vessels were present in *A. nilotica*, *A. mellifera*, *P. chilensis*, *A. seyal* and *A. leiocarpus*, and oblique vessel arrangement was observed in *P. chilensis*, *A. mellifera* and *E. camaldulensis*. Vessels in clusters and radial arrangement were seen in *B. aegyptiaca* while in *A. Senegal*, only tangential vessels arrangement was observed.

Thick banded fibers were seen in all of the studied species. Also, longitudinal parenchyma was observed in all of the species except *E. camaldulensis*, where parenchyma was not seen even by the aid of hand lens.

Confluent and aliform longitudinal parenchyma was distinct in all species except *B. aegyptiaca*, which had banded parenchyma and *A. leiocarpus*, which had vasicentric parenchyma that could be seen by the hand lens.

The studied species showed great variation in ray size. Rays were seen in all of the studied species except *A. leiocarpus*, where the rays were very difficult to see even by the hand lens. The studied species showed great variation in ray size. Broad rays could be seen clearly by naked eye without lens such as in *B. aegyptiaca*, *A. senegal* and *A. nilotica*, but moderately broad rays could not be seen clearly by naked eye but can be seen clearly by lens was observed in *A. mellifera* and *P. chilensis*. Narrow rays, which could not be seen clearly (hardly seen) by naked eye or with lens was observed in *A. seyal* and *E. camaldulensis*.

The eight studied charcoal-producing trees showed greater variation in the proportion of cell types than in the size (diameters) of the various cell types. The variation in the proportion of cell types is, to a great extent, associated with (and affected by) the variation in the number of cells per unit volume or area of these cell types, and affects the proportion of wood substance found in the wood tissue. The studied species also showed considerable variations in wood macro-structure.

Differences in the wood anatomical properties of some species between the current study and previous ones are brought about by the fact that wood is a biological product. Being a metabolism-product of the living trees, wood is an inherently variable substance among trees of the same species. Its structural properties are subject to wide variation brought about by the physiology of trees and external factors affecting its growth. This explains some of the variation in wood structure of the same species in various studies. Moreover, as noted by many authors (e.g. Panshin and de Zeeuw. 1980; Koch. 1985), there is variability in wood characteristics within individual trees, which is fundamentally related to change resulting from

aging of the cambium and modification imposed on the cambial activity by environment condition. Hence, the sampling procedure (including samples position within trees) introduces another element of variation among different studies. It worth noting that the wood material used in the current study was either partially or entirely composed of branch wood.

4.4. Variation in Charcoal Macro-Structure among Species

During the carbonization process, considerable anatomical changes occurred. Some of the details of the anatomical characteristics that were easily observed on the transverse surfaces of wood could not be seen on the transverse surface of charcoal samples produced from the studied species. Growth rings, which were indistinct only on the wood transverse surfaces of *P. chilensis*, *A. nilotica* and *A. leiocarpus*, turned out to be indistinct also on the charcoal surfaces of *A. seyal*, *P. chilensis*, *E. camaldulensis* and *B. aegyptiaca*.

Fibers which were distinctly seen on wood samples as thick bands were not distinct in the charcoal samples; they did not show up. Also the changes included the rays, which appeared as bright lines in the charcoal macro structure

While in wood samples vessels were distinct and their arrangements could be distinguished, in charcoal samples they could be seen but their arrangements were difficult to be distinguished. However, it was possible to distinguish solitary vessels from the other arrangements (vessels in groups). This was probably, noted by Jones Chaloner. (1991) and Jones. (1993) due to the homogenization of the cell walls, in which the middle lamella loses its identity and fuses with the two adjacent secondary wall layers. Therefore, in all of the studied species the vessels appeared as solitary, except in *E. camaldulensis* where vessel cluster were observed.

Variations were detected between the eight species in charcoal macro-structure. Differences among species included growth rings, which were distinctly present in *A. leiocarpus*, *A. nilotica*, *A. mellifera* and *A. Senegal*, but not distinct in *A. seyal*, *E. camaldulensis*, *P.chilensis* and *B. aegyptiaca*. Longitudinal parenchyma was not seen in the charred samples of *A.leiocarpus*, *A. nilotica* and *B. aegyptiaca*. However, *A. senegal* and *P. chilensis* had banded parenchyma, but *A. seyal* and *A. mellifera* had vasicentric parenchyma.

All of the species had distinct rays except *A. leiocarpus*, where rays were not distinct even with the aid of a lens. *B. aegyptiaca* and *A. seyal* had broad rays that are easily seen by the naked eye, but *P. chilensis* had very narrow ray that are hardly seen by the lens. However, *A. mellifera*, *A. Senegal*, *A. nilotica* and *E. camaldulensis* had narrow rays

From the forgoing, it is clear that some macro-structural similarities and dissimilarities were detected on the transverse surfaces of the charcoal produced from the eight studied species. The charcoal retained variation this may help mid find some anatomical characteristics to allow identification of the wood from which it came. A dichotomous key was developed to help in identifying the wood species from which the charcoal was produced. The eight species were first divided into two major groups depending on the presence or absence of growth rings. Each group was sub divided according to the distinctiveness and size of the rays. Then the lastly each of these subgroups was further divided depending on longitudinal parenchyma is seen or not seen on the transverse charcoal surface. The identification key is illustrated in Figure 4.9.

Table 4-1 .Summary of vessels qualitative anatomical characteristics of eight hardwood species

Species	Solitary	Radial multiples	Clusters	Tangential multiples	Oblique multiples	Wall pitting	Oblique arrangement	Gum
<i>A. senegal</i>	+++	2-3	+	+	-	Scalariform	-	+
<i>A.nilotica</i>	+++	2-3	+	-	-	Scalariform	-	+
<i>A.seyal</i>	+++	2-4	+	+	+	Alternate	-	+
<i>A.mellifera</i>	+++	2-3	+	-	+	Scalariform	-	+
<i>P.chilensis</i>	+++	2-3	+	-	+	Alternate	-	+
<i>E.camaldulensis</i>	+++	2	+	+	-	Alternate	-	+
<i>B. aegyptiaca</i>	+++	2	-	+	+	Alternate	-	-
<i>A. leiocarpus</i>	-	2-5	+	-	-	Alternate	-	+

+ = The character is present occasionally.

+++ = The character is present dominantly.

- = The character is absent.

Table 4.2. Average quantitative anatomical characteristics of vessels for eight hardwood species

Species	Horizontal diameter (mm)	Vertical diameter (mm)	Horizontal double-cell wall (mm)	Vertical double-cell wall (mm)	Lumen diameter (mm)	Mean horizontal free path (mm)	Mean vertical free path (mm)	Number per mm²	Volume fraction (%)
<i>A. senegal</i>	0.097	0.103	0.009	0.003	0.106	0.62	0.59	13.59	18
<i>A. nilotica</i>	0.130	0.120	0.03	0.02	0.10	0.21	0.23	28.54	19
<i>A. seyal</i>	0.08	0.230	0.01	0.16	0.07	0.403	0.4	23.30	18
<i>A. mellifera</i>	0.117	0.116	0.002	0.001	0.115	0.79	0.80	9.48	16
<i>P. chilensis</i>	0.102	0.090	0.009	0.001	0.093	0.70	0.76	11.86	15
<i>E. camaldulensis</i>	0.11	0.13	0.03	0.05	0.08	0.28	0.34	29.57	25
<i>B. aegyptiaca</i>	0.083	0.068	0.027	0.012	0.056	0.693	0.844	15.57	11
<i>A. leiocarpus</i>	0.210	0.220	0.2	0.3	0.19	0.01	0.09	35.30	22

T able 4.3. Summary of fiber qualitative and quantitative anatomical characteristics of eight hardwood species

Species	Horizontal diameter (mm)	Vertical diameter (mm)	Lumen diameter (mm)	Horizontal double-cellwall (mm)	Vertical double-cellwall (mm)	Number per mm²	Volume fraction (%)	Gum	Crystal
<i>A.senegal</i>	0.016	0.017	0.013	0.004	0.003	1495.04	38	-	+
<i>A.nilotica</i>	0.017	0.018	0.014	0.003	0.004	1487.96	33	-	+
<i>A. seyal</i>	0.13	0.13	0.031	0.1	0.1	188.78	37	-	+
<i>A.mellifera</i>	0.012	0.012	0.013	0.013	0.01	2255	34	+	-
<i>P. chilensis</i>	0.019	0.018	0.014	0.005	0.004	1414.17	47	+	-
<i>E. camaldulensis</i>	0.07	0.06	0.05	0.02	0.01	137.07	27	-	-
<i>B. aegyptiaca</i>	0.017	0.018	0.014	0.003	0.004	1280.96	31	-	-
<i>A. leiocarpus</i>	0.014	0.014	0.011	0.003	0.003	1722.26	24	+	-

+ = The character is present occasionally.

+++ = The character is present dominantly.

- = The character is absent.

Table 4.4. Average quantitative anatomical characteristics of longitudinal parenchyma for eight hardwood species

Species	Horizontal diameter (mm)	Vertical diameter (mm)	Lumen diameter (mm)	Horizontal double-cellwall (mm)	Vertical double-cellwall (mm)	Number per mm²	Volume fraction (%)
<i>A. senegal</i>	0.017	0.018	0.013	0.005	0.004	974.09	25
<i>A. nilotica</i>	0.02	0.019	0.011	0.009	0.008	1487.22	25
<i>A. seyal</i>	0.16	0.15	0.04	0.12	0.11	1060.7	23
<i>A. mellifera</i>	0.02	0.02	0.014	0.006	0.006	693.39	18
<i>P. chilensis</i>	0.017	0.017	0.011	0.006	0.006	1257.65	26
<i>E. camaldulensis</i>	0.19	0.16	0.04	0.15	0.12	104.14	21
<i>B. aegyptiaca</i>	0.019	0.019	0.013	0.006	0.0006	1125.39	31
<i>A. leiocarpus</i>	0.014	0.015	0.011	0.003	0.004	1010.61	17

Table 4.5. Summary of longitudinal parenchyma qualitative anatomical characteristics of eight hardwood species

Species	Confluent	Aliform	Banded	Aliform-confluent	Vasicentric.	Diffuse	Apo-tracheal	Gum	Crystal
<i>A. senegal</i>	+++	+	++	+	-	-	-	-	+
<i>A. nilotica</i>	+++	+++	-	-	+	-	-	-	+
<i>A. seyal</i>	+++	+	-	+	-	-	-	+	+
<i>A. mellifera</i>	+	+	+++	-	-	-	-	-	-
<i>P. chilensis</i>	+	+	+++	-	-	-	-	-	-
<i>E. camaldulensis</i>	-	-	-	-	-	+++	-	-	-
<i>B. aegyptiaca</i>	-	-	+	-	-	In aggregate	+++	-	-
<i>A. leiocarpus</i>	-	-	-	-	+	++	+++	-	-

+ = The character is present occasionally.

+++ = the character is present dominantly.

- = The character is absent.

Table 4.6. Summary of ray qualitative and quantitative anatomical characteristics of eight hardwood species

Species	Type	Dieseriate	Triseriate	Uniseriate	Multiseriate	Number per mm ²	Volume fraction %	Gum	Crystal
<i>A. senegal</i>	homogenous	+++	+++	-	+	8.70	20	+	+
<i>A. nilotica</i>	homogenous	+	+++	+	+++	30.17	23	-	-
<i>A. seyal</i>	homogenous	-	-	-	+++	10.70	21	-	+
<i>A. mellifera</i>	homogenous	++	+++	-	+	7.16	19	-	-
<i>P. chilensis</i>	homogenous	+++	+++	+	-	13.10	26	-	-
<i>E. camaldulensis</i>	homogenous	+	+	+++	-	21.65	27	+	-
<i>B. aegyptiaca</i>	homogenous	-	-	-	+++	5.01	26	+	-
<i>A. leiocarpus</i>	Heterogeneous	-	-	+++	-	34.75	29	+	-

+ = the character is present occasionally.

+++ = the character is present dominantly.

- = the character is absent.

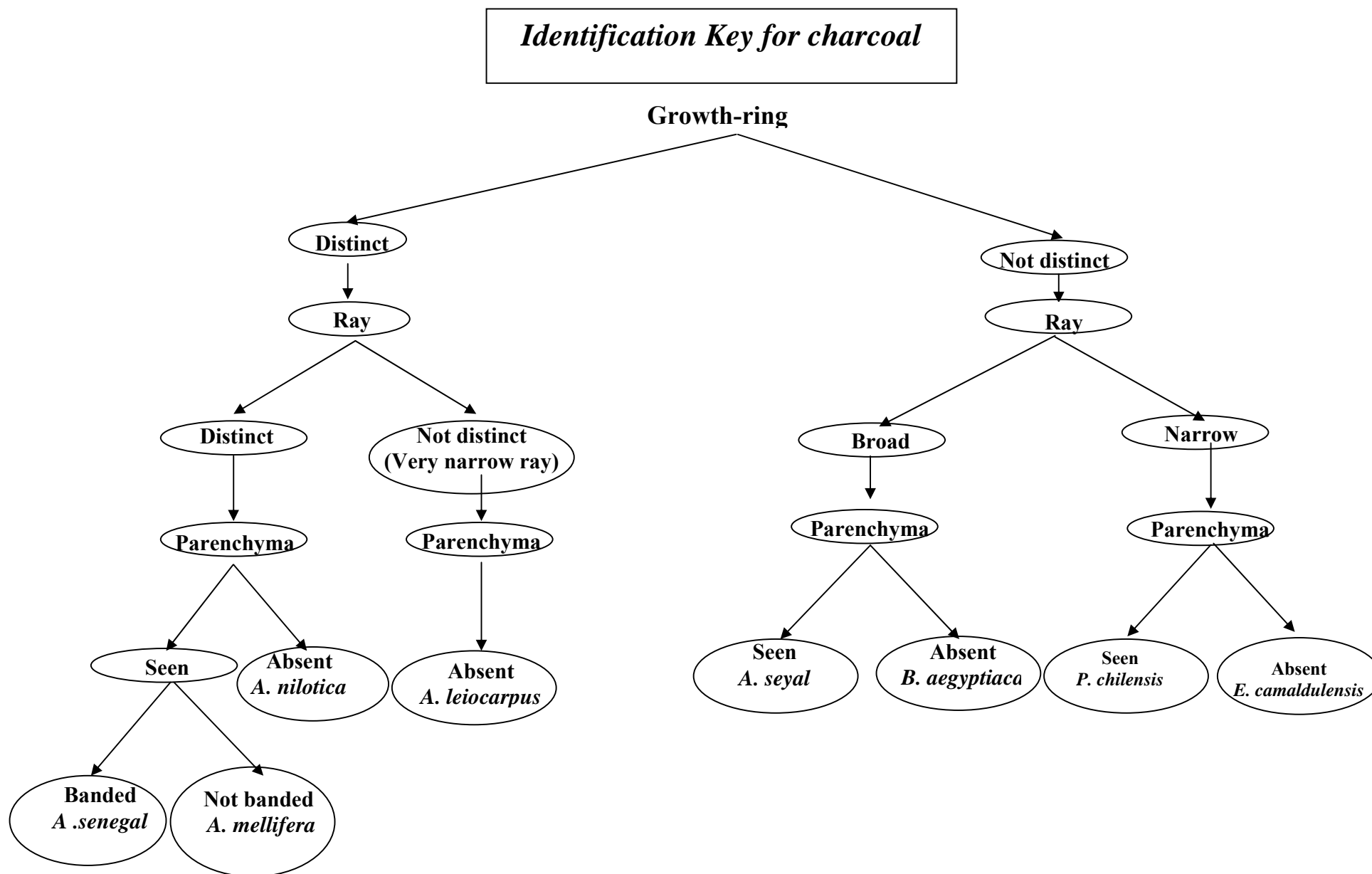


Figure 4.9 Identification Key for charcoal

CHAPTER V

CONCLUSIONS and RECOMMENDATION

5.1. Conclusions

There were great variations among charcoal-producing species in the proportion of wood substance and in the wood anatomical characteristics (quantitative and qualitative) of all wood cell type.

In charcoal the fibers were not distinct. Growth rings, rays, parenchyma and vessels could not be seen in the charcoal although they were distinct in the wood of some species.

The charcoal did not retain enough anatomical characteristics to allow accurate identification of the wood from which it came using a dichotomous key.

5.2. Recommendation

- Rather research is needed to study wood and charcoal anatomical characteristics of other charcoal-producing species that are not included in this study.
- Further research is needed to study the qualitative and quantitative structure of charcoal to provide more information to facilitate better understanding of the changes in anatomical structure of carbonized wood and enhance the identification procedure of charcoal produced in the Sudan.
- Further research is needed to study the structure of charcoal should be studied by using a scanning electron microscope.

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